

# A review of the stratigraphy and trilobite faunas from the Cambrian Burj Formation in Jordan

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**SYNOPSIS.** The Burj Formation in Jordan, and its correlatives in surrounding countries, is a Cambrian marine carbonate and siliciclastic deposit which transgressed widely but relatively briefly southwards across the Arabian craton. Three members (Tayan Siltstone, Numayri Dolomite and Hanneh Siltstone) are here formally described from outcrops at the southern end of the Dead Sea, Jordan. Trilobites from the Burj Formation are described and are all considered to be earliest Middle Cambrian in age, rather than Lower Cambrian, as previously recorded.

## INTRODUCTION

The lithostratigraphy of the Cambrian System in Jordan has been studied extensively (Bender 1974; Powell 1989). In outline, Neoproterozoic complexes (Ibrahim & McCourt 1995) are overlain by the Ram Group, which consists dominantly of sandstone units and includes a fossiliferous carbonate-rich intercalation now known as the Burj Formation. Faunas from the Burj were examined by various workers who tentatively assigned early to mid- or late Cambrian and Ordovician ages to them. Contemporaneous beds which crop out at Timna in the southern Negev (south Israel) have been reviewed by Weissbrod (1970) and Parnes (1971); the Timna outcrop is generally accepted as being offset from the Dead Sea outcrop in Jordan by a left-lateral (sinistral) displacement of approximately 105 km along the Dead Sea – Gulf of Aqaba Rift fault (Freund *et al.*, 1970).

Brachiopods and trilobites recorded from the Burj Formation by Blanckenhorn (1912, 1914) were described by Richter & Richter (1941), who reviewed other work in that region. They rejected earlier opinions that the faunas ranged in age from early in the Cambrian to Ordovician, and regarded the records known to them as close to the Lower-Middle Cambrian boundary, and probably highest Lower Cambrian. Parnes (1971) described further material, especially from the southern Negev, and reviewed earlier work. After comparing material from the east side of the Dead Sea and from Timna in the southern Negev with Hupé's faunal succession for Morocco (Hupé 1960), he proposed a more elaborate biostratigraphy extending through much of the Lower Cambrian. Cooper (1976) studied the brachiopod faunas and relied on Parnes' work to indicate their late Early Cambrian age.

Subsequent seismic studies and the examination of deep boreholes has greatly extended knowledge of the Cambrian succession in Jordan (Andrews 1991). Although the macrofossils were considered to indicate a late Early Cambrian age for the formation, marine palynomorphs described from boreholes NH-1, TS-11, WS-3 in Jordan (Fig. 2), occurring in palynozone JC-1 of Keegan *et al.* (1990), were assigned an early Middle Cambrian age, especially on account of the occurrence of acritarchs known from the Oville Formation in Spain, which is assigned to the Leonian Stage (Table 1) and the overlying Caesaraugustian Stage (Liñán *et al.* 1993).

Whilst these reports suggested that the biostratigraphy of the Cambrian rocks of Jordan and Israel is complex, sedimentological syntheses, coupled with work on trace fossils, supported a relatively simple model in which a Cambrian marine transgression introduced a tongue of marine strata onto the Arabian craton (Selley 1972; Amireh *et al.* 1994), though those authors did not attempt to integrate their syntheses with the known biostratigraphy.

We have examined new material from the Dead Sea area and reviewed older work, especially in the light of recent study of the Moroccan sequences (Geyer 1990a, 1990b; Sdzuy 1995), and believe that the palaeontological evidence can be reconciled with the recent stratigraphical and sedimentological syntheses. We conclude (following Amireh *et al.* 1994) that near the beginning of Middle Cambrian times a marine incursion transgressed from the north or north-west onto earlier Cambrian fluvialite deposits on the Arabian craton. It introduced various lithofacies comprising locally fossiliferous shallow-water carbonate and siliciclastic deposits. Soon afterwards a fall in sea-level and increased sediment from the Arabian craton resulted in a return to fluvialite sedimentation which continued in central-south Jordan until the Ordovician.

## LITHOSTRATIGRAPHY


**LOCALITIES.** Owing to a lack of a standard transliteration of Arabic place names, confusion has arisen regarding the names of wadis and other features referred to by various authors (for example Wadi Qunai has been recorded as Wadi Quni, Wadi Kneye, Wadi Gineya). We adopt the standard names used by the Geology Directorate, Natural Resources Authority, Jordan.

Localities studied during this work are located to within 500 m using the Palestine National Grid (PNG). Localities referred to by previous authors are not always precise, and here we have endeavoured to give a grid reference based on their descriptions.

## Burj Formation

The Burj Dolomite-Shale Formation, hereafter referred to as the Burj Formation, forms a prominent cliff-like feature between the siliciclastic Salib Arkose and Umm Ishrin formations in the type

**Table 1** Correlation of the Lower-Middle Cambrian interval in Jordan with selected successions elsewhere, based on trilobite faunas.

PERIOD/ EPOCH			SPAIN	MOROCCO	JORDAN	SIBERIA	SOUTH CHINA
CAMBRIAN	MIDDLE*	MIDDLE#	LEONIAN (with <i>Paradoxides mureoensis</i> )	O. frequens Zone		Triplagnostus gibbus Zone	Redlichia nobilis Zone
				Cephalopyge Zone (with <i>Schistocephalus</i> cf. <i>juvenis</i> )			
	LOWER*	LOWER#	BILBILIAN  (with <i>Realspiss</i> & <i>Kingaspiss</i> )	Hupeolenus Zone	<i>P. antiquus</i> <i>K. campbelli</i> <i>Realspiss</i> <i>O. palmeri</i>	P. antiquus Zone	Megapalaeolenus Zone
			MARIANIAN	BANIAN Sectigena Zone			
						Drepanuroides Zone	

\*Middle Cambrian of Szduy (1961); #Middle Cambrian of Geyer (1990)

area adjacent to the Dead Sea. The general stratigraphical setting is shown in Fig. 1. The best exposures are southwards from Wadi Issal (Edh Dhira) to the Feinan-Dana area (Figs 2-4). It also crops out a few kilometres north of Wadi Zarqa Ma'in where only the upper part of the formation is exposed. Between the Feinan-Dana area and Wadi Quseib the formation is represented by coeval marine siliciclastic deposits (Bender 1974; Powell 1989) but it is absent south of the latter locality and in the Southern Desert where the Umm Ishtar Sandstone directly overlies the Salib Arkose (Fig. 4). The formation has been penetrated in deep boreholes (Fig. 2) north-west of Amman (e.g. Suweileh 1, SW-1) and in the southern Wadi Sirhan (e.g. Wadi Sirhan 3, WS-3) where marine carbonate and siliciclastic deposits, equivalent to the Burj Formation, are reported to be at least 135 m thick (Andrews 1991). The Burj Formation, as defined by Powell (1989) and adopted in this paper, is probably thicker than recorded in these boreholes (Fig. 2, Fig. 4, section 1) because in them the top of the formation was generally taken at the top of the middle Numayri Dolomite Member, the Hanneh Siltstone Member not being recognised. This lower boundary produces a marked geophysical log response and is a convenient marker horizon for subsurface studies (Andrews, 1991). However, in the reference borehole Wadi Sirhan-3 (WS-3, Fig. 2) Andrews (1991: fig. 10) attributed a succession of marine claystone, siltstone and sandstone intercalated with dolomitic limestone and shelly, trilobite-rich, oolitic grainstones, that overlie the Numayri Dolomite, to the upper part of the Burj Formation. We concur with this interpretation and, furthermore, consider these upper beds to be a lithofacies equivalent of the carbonate/siliciclastic beds in the upper part of the Burj Formation (possibly equivalent to the Hanneh Member), as described herein from the outcrop at Zarqa Ma'in (Figs 2, 4).

The type section in the Safi area is Khirbet El Burj, Locality 1 of Blanckenhorn (1912) ('Chirbet el-Burdsh' in Richter & Richter 1941). The full sequence is not well exposed at this locality so

reference sections were proposed in the same area at Wadi Saramuj (PNG 198:047) (Powell, 1988) and east of Safi Potash Works (PNG 201:055) (Fig. 3). Fig. 5 shows a composite section in the type area and the Wadi Zarqa Ma'in section provides a useful reference section for the upper part of the formation in the north-central area (Fig. 6).

**THICKNESS.** The formation ranges in thickness, at outcrop, from zero in the southern desert to 120 m in the Safi area (Fig. 4). Thicknesses recorded in deep boreholes near Amman (Fig. 2) are based on the top of the formation being taken as the top of the Numayri Dolomite Member (*sensu* Andrews, 1991; see above), and are consequently minimum thicknesses, as follows: 124 m in Suweileh 1 Borehole (SW-1 in Fig. 2) and 135 m in Safra 1 Borehole (SA-1) (Bender 1974). Correlation of the outcrop and boreholes in the Wadi Zarqa Ma'in area (GTZ-2D Borehole; Masarwah 1987) suggests that the 'marine' Burj Formation is about 170 m thick, and comprises a number of carbonate units intercalated with marine siliciclastic beds; similar lithofacies, up to 96 m thick, were reported from a deep borehole (WS-3; Fig. 2) in the southern Wadi Sirhan area (Andrews 1991). In northern Syria the Burj carbonates have been proved up to about 200 m thick in Khanaser 1 Well, and have been widely traced throughout that country on seismic lines (Best *et al.* 1993).

**NOMENCLATURE.** The formation was defined by Quennell (1951) and the name is taken from the ruins of Al Burj ('the tower') in the lower course of Wadi Al Hisa (also Hesa or Hasa). The dolomite-limestone ('Wadi Nasb Limestone') was first recorded by Hull (1886) in this area, and Blanckenhorn (1914) described a fuller sequence of 30 m of red and green micaceous shales and 'marls' ('Hasa Shales' of Wetzell & Morton, 1959) overlain by 30 m of limestone and dolomite; this definition was followed by Burdon (1959), who, with Quennell (1951), assigned group status to it.



AGE		JORDAN (after Lloyd, 1969; Selley, 1970; Powell, 1988; Masri, 1988)		TIMNA (ISRAEL) (Weissbrod, 1970)	
SILURIAN LANDOVERY	G R O U P	KUSHSHA SANDSTONE FM.			
		MUDAWWARA SANDSTONE FM.		Ratiya Sst. Mbr. Batra Mst. Mbr. Tubelliyat Sst. Mbr.	
C A M B R I A N CARASH	K H R E I M	DUBEIDIB SANDSTONE FM.		'upper' 'middle' 'lower'	
		HISWAH SANDSTONE FM.			
		UMM SAHM SANDSTONE FM.			
O R D O V I C I A N ARENG	G R O U P	DISI SANDSTONE FM.			
		UMM ISHRIN SANDSTONE FM.		NETAFIM FM. SHEHORET FM.	
C A M B R I A N LATE	R A M	BURJ FM.		TIMNA FM. Mikhot Mbr. Nehushtan Mbr. Nimra Mbr. Hakhlil Mbr.	
		SALIB ARKOSE FM.		AMUDEI SHELOMO FM.	
C A M B R I A N EARLY	Y A M S U F G R O U P	FEINAN GRANITE & AHEIMIR VOLCANICS		ZENEFIM/EILAT FM.	
		HIYALA VOLCANICLASTICS SARAMUJ CONGLOMERATE			
A Q A B A C O M P L E X		PRE-CAMBRIAN BASEMENT			

Fig. 1 Stratigraphical framework of the Cambrian and Ordovician rocks in Jordan and Israel (after Powell, 1989).

Bender (1974) termed it the 'dolomite-limestone-shale formation' and followed the definition of Blanckenhorn (*op. cit.*). However, in lithological sections and maps Bender (1968) included about 30 metres of overlying shales and sandstone (cb 2+1) within the same formation. The latter definition was adopted by Powell (1988) and is followed here, although in the subsurface Andrews (1991) placed the top of the formation at the top of the Numayri Dolomite. Powell recognised three members, in upwards sequence: the Tayan Siltstone, Numayri Dolomite and Hanneh Siltstone, described below, from the type area near Safi (Figs 3–5).

The Burj Formation is equivalent to the Timna Formation (Fig. 1) on the west side of the Wadi Araba, at Timna, near Eilat (Weissbrod, 1970). The four formations of Parnes' (1971) review – the Hakhlil, Nimra, Nehushtan and Mikhot formations – are here treated as members of the Timna Formation.

**Tayan Siltstone Member.** This ranges in thickness from 18–20m, and consists of finely laminated green, mauve and red or buff, micaceous, fine-grained sandstone and siltstone.

The name is taken from Wadi Tayan (PNG 201.5:061.5) where the member is well exposed (Figs 3, 5). Straight-crested, oscillation (wave) ripples, ripple cross-lamination, and parallel lamination are common. The thicker sandstone beds have small-scale, bimodal, trough cross-bedding with mudstone intraclasts. Thin dolomite

lenses are present near the middle of the member, and indeterminate surface burrows are common on some bedding planes. Secondary gypsum veins and laminae occur along joints and bedding planes. The lower boundary is defined at the base of mauve-red micaceous siltstone and fine-grained sandstone that overlies yellow-brown medium-grained trough cross-bedded sandstone of the Salib Arkose Formation. The upper junction with the Numayri Dolomite is taken at the base of the first thick bed of limestone or dolomitic limestone, which in places is sandy, with low-angle erosive scours and ripple cross-lamination.

**Numayri Dolomite Member.** The member (38 to 60 m thick) forms a prominent, brown-weathering cliff along the outcrop. The name derives from Wadi Numayri (PNG 203:059) where it is well exposed. The carbonate varies from limestone to dolomitic limestone and dolomite with wackestone and packstone textures; clasts include oolites and bioclasts (brachiopods, hyolithids and trilobites). The vertical sequence of microfacies varies throughout the outcrop, but the following generalised sequence is common to most exposures in the Safi – Wadi Numayri areas: the basal 5 m has a high proportion of fine-grained quartz sand with ripple cross-lamination and sandstone intraclasts; this passes up to a massive, brown-weathering (grey) dolomite and dolomitic limestones (microcrystalline, wackestone and packstone textures), 20–30 m thick, with glauconite peloids, cross-laminated and parallel-laminated oolites, oncolites (algal-coated grains), and lenses of disarticulated brachiopods and rare trilobite fragments. Irregular lenses of orange-brown dolomite are intercalated with the clast-rich carbonates. There is an increase in quartz sand above, with alternating sand-rich and sand-poor lenses; the sand-rich lenses are cross-laminated, with shallow erosive scours and they weather as prominent dark brown chert-like bands, 2–3 m thick. Beds of oolitic, oncolitic or brachiopod shell-rich dolomitic limestone are locally present at the top of the member in the south. Near Safi (Figs 4, 5), the member is thicker (58 m) and the upper part includes beds of cross-laminated oolitic limestone, algal stromatolites, and thin (40 cm) beds of green calcareous siltstone with abundant trilobite fragments, hyolithids and glauconite peloids. Here, the sequence is capped by a distinctive orange-weathering dolomite. The textures and fine details of the carbonates are often obscured at outcrop by ubiquitous brown staining. The boundary with the green, red or grey micaceous siltstone or fine-grained sandstone of the overlying Hanneh Siltstone is sharp.

**Hanneh Siltstone Member.** The name is taken from Jibal Tabaq Hanneh (PNG 201.5:060.0), on the north side of Wadi Numayri (Fig. 3). The lithology of this member is similar to the Tayan Siltstone, but there is a higher proportion of sand over silt-grade siliciclastic rocks. It was not previously included in the formation, except for the maps and lithological sections in Bender (1968). It is about 30 m thick in the Wadi Saramuj area and 35 m thick in the cliffs below Jibal Tayan. The base is sharp, and is taken where red-grey or green parallel-laminated to ripple cross-laminated micaceous siltstone overlies the carbonate (Numayri Dolomite). The beds above are laterally variable, but predominantly comprise thinly bedded green or red-green, micaceous, ripple cross-laminated siltstone and micaceous fine-grained sandstone, with thicker beds (0.5 m) of buff, medium-grained, bimodal trough cross-bedded sandstone; mudstone and dolomite clasts are common at some horizons. Small, circular surface-burrows and *Rusophycus*(?) traces are present on siltstone surfaces. The top is clearly marked by the overlying red-brown, massive, medium- to coarse-grained, large-scale trough cross-bedded sandstone (Umm Ishrin Formation).

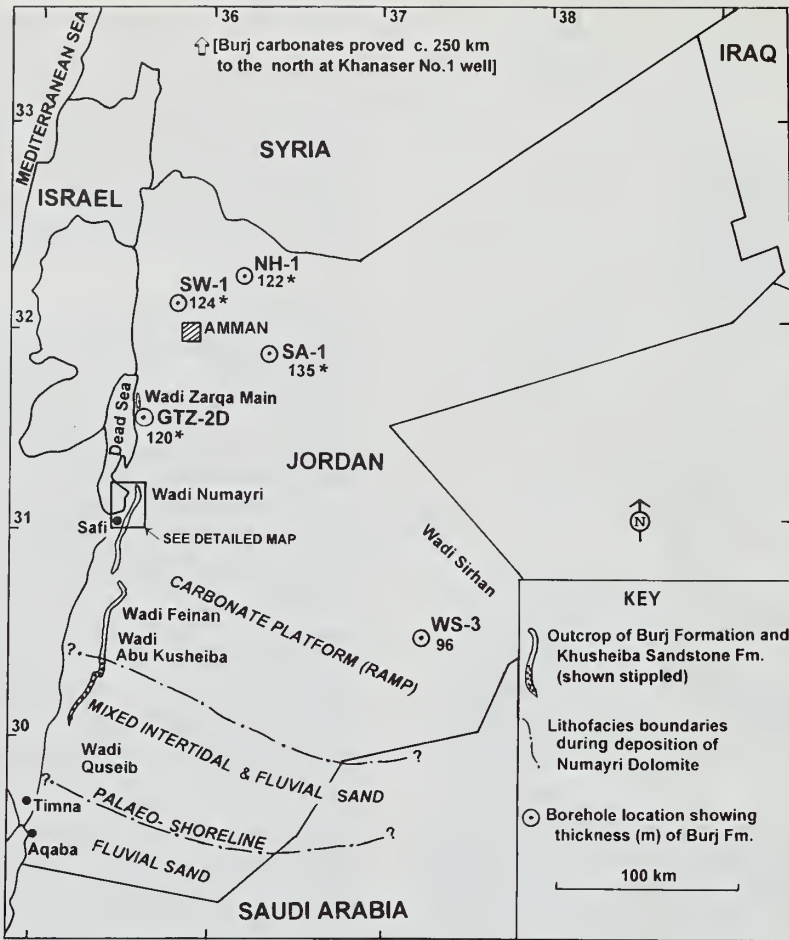


Fig. 2 Sketch-map showing the outcrop of the Burj Formation in Jordan and the position of localities mentioned in the text. Lithofacies boundaries obtaining during deposition of the Numayri Dolomite are shown for southern Jordan. Degrees of latitude and longitude are shown at the edge of the map. Selected boreholes: GTZ-2D = Geothermal Zarqa Main-2D, NH-1 = Northern Highland 1, SA-1 = Safra 1, SW-1 = Suweileh 1, WS-3 = Wadi Sirhan 3. An asterisk indicates the minimum thickness of the Burj Formation in boreholes where the Hanneh Siltstone was not recognised and the top of the formation was taken at the top of the Numayri Dolomite Member (*sensu* Andrews, 1991).

**Zarqa Ma'in outcrop.** The outcrop 1 km north of Wadi Zarqa Ma'in (Fig. 2) is incomplete as only the upper part of the formation is exposed (Fig. 6). The succession probably belongs to the uppermost part of the Numayri Dolomite Member and/or the Hanneh Siltstone Member. At this locality about 3 m of grey finely laminated, fine-grained quartz arenite with burrows and ripple cross-lamination, at the base, are overlain by intercalated green-grey, cross-laminated siltstone, fine-grained sandstone and shelly grainstone, passing up to oolitic packstone and cross-bedded trilobite grainstone (4 m). The eroded top of the latter is overlain by marine siliciclastic rocks with bimodal cross-bedding, trilobite traces and *Harlania* burrows (24.5 m). A second carbonate unit (3 m) follows above, consisting of trilobite, brachiopod, hyolithid grainstones, oolitic and cross-bedded in part, and this in turn is overlain by about 50 m of marine siliciclastic strata. These consist of fine- to medium-grained bimodal trough cross-bedded sandstones with small dune forms, intercalated with parallel laminated, ripple cross-laminated, green to mauve, micaceous siltstone and fine-grained sandstone with oscillation and interference ripples. Sparse surface traces and burrows are present in the fine-grained lithologies.

## ENVIRONMENT OF DEPOSITION

Early workers (Hull 1886; Blanckenhorn 1914) recognised the marine nature of the formation by the presence of brachiopods, trilobites and hyoliths in the carbonates; subsequently, marine calcareous algae, including *Girvanella* sp., were identified by J. H. Powell in thin sections of the oncolite lithofacies. The siliciclastic strata contain an ichnofauna characteristic of shallow-water environments, including the arthropod resting and crawling traces *Rusophycus* and *Cruziana*, which are common on some of the bedding planes in the Tayan Siltstone and Hanneh Siltstone members, and sub-vertical burrows, including *Skolithos*. Amireh *et al.* (1994) also identified *Diplocraterion* and *Tigillites* from the Hanneh Siltstone at Wadi Numayri, and *Cruziana aegyptica* Seilacher (1990), *Diplocraterion* sp. and *Scolecia* sp. from siliciclastic rocks at Wadi Quseib.

From the base upwards, a clear pattern of marine transgression and regression is indicated by the fauna and sedimentary structures in the Wadi Numayri type area (Powell 1988, 1989; Amireh *et al.*, 1994). The Tayan Siltstone overlies medium-grained sandstones

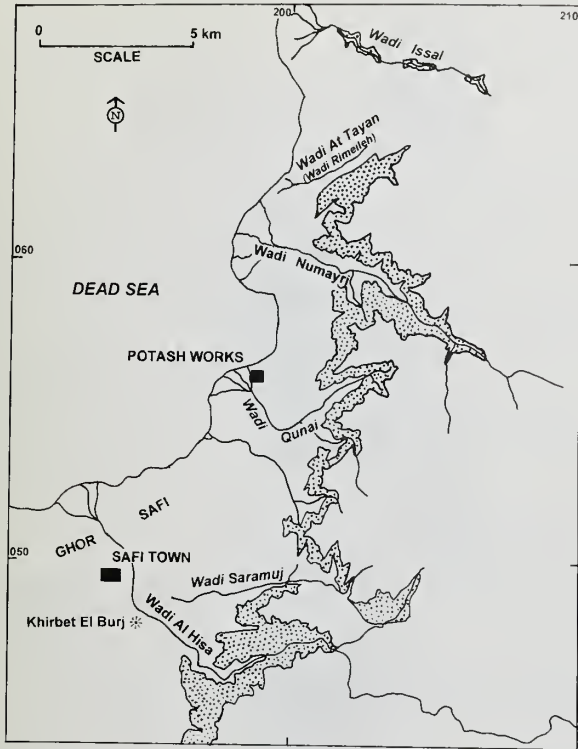


Fig. 3 Generalised map of the Safi area, southern Dead Sea, showing the outcrop of the Burj Formation (stippled), and the localities mentioned in the text. The grid is Palestine National Grid (PNG); geological boundaries after Powell (1988).

with laterally accreted channel-fill, probably of meandering-river or tidal-flat origin. Wave ripples, small-scale bidirectional cross-bedding, intra-clasts, burrows and thin dolomite laminae in the Tayan Siltstone suggest a marine incursion over a low-lying alluvial plain, and deposition in a shallow subtidal to intertidal environment. The succeeding carbonates (Numayri Dolomite) mark the maximum phase of the transgression. Oncolites, oolites, disarticulated brachiopod shell lenses, low-angle cross-bedding with shallow scours in the purer carbonates, and ripple cross-lamination in the siliciclastic-rich carbonates indicate deposition in a warm, shallow, carbonate lagoon, with periodic storm-events redistributing oolites, bioclasts and quartz sand. Domal, laterally linked stromatolites indicate intertidal to supratidal conditions near the top of the unit. The Hanneh Siltstone represents the regressive phase marked by an influx of siliciclastic sediment, derived from the south, into the shallow carbonate platform. Sedimentary structures and trace fossils similar to these in the Tayan Member suggest deposition in a tidally dominated shoreline. Subsequently, coarse-grained, trough cross-bedded sand was deposited, by braided to meandering rivers, which prograded over the wedge of marine sediments. In central and south Jordan, continental fluvial deposition continued through the Umm Ishrin Formation into the Disi Formation (Selley 1972). Trace fossils in thin marine intercalations suggest that the Disi Formation is of early Ordovician age (Seilacher 1970).

At Wadi Zarqa Ma'in the exposed carbonates show an upward-coarsening (shoaling) trend from shallow-water ripple cross-laminated siltstones and sandy carbonates to oolitic shelly packstones and cross-bedded (trilobite-rich) grainstone deposited in the shallow subtidal zone. Bi-directional dune sandstones with an erosive base, and bioturbated ripple cross-laminated siltstones above, suggest an influx of sand from prograding rivers along the shallow, tidally influenced coastal margin. The upper carbonate bed marks a brief transgressive pulse and was deposited in a shallow subtidal to

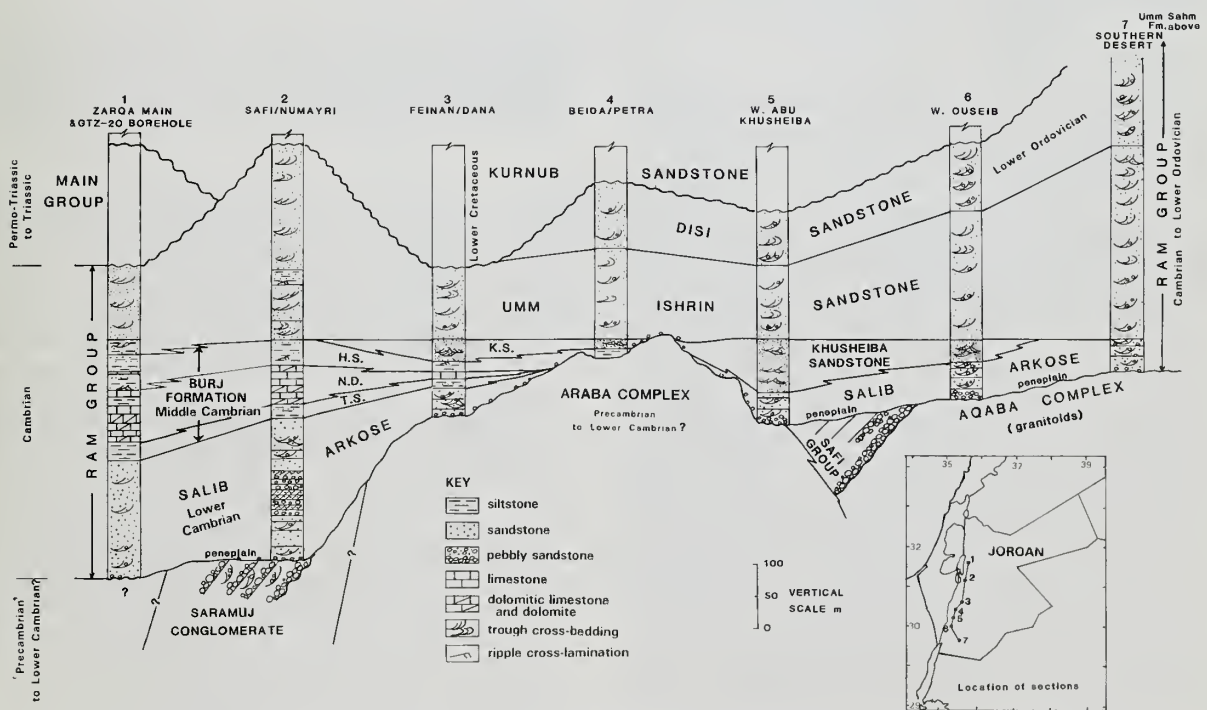


Fig. 4 Correlation of the Ram Group, including the Burj Formation, along the margin of the Dead Sea - Gulf of Aqaba Rift. Inset map shows the location of the sections. HS = Hanneh Siltstone, KS = Kusheiba Sandstone, ND = Numayri Dolomite, TS = Tayan Siltstone (after Powell, 1989).



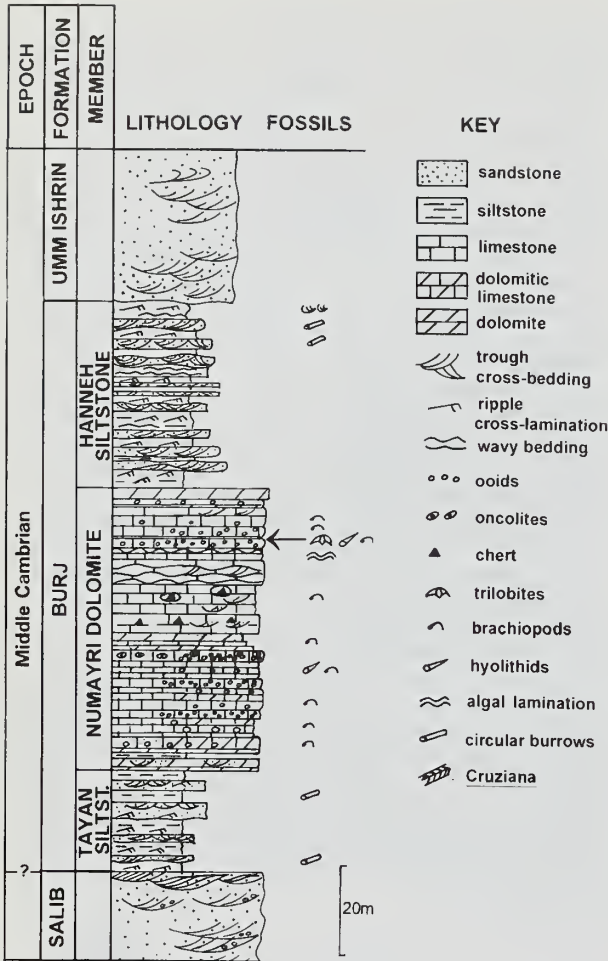


Fig. 5 Composite lithological section of the Burj Formation in the Safi area, southern Dead Sea. Arrow shows the level with trilobites in Wadi Qunai (after Powell, 1989).

intertidal environment; it was succeeded by a further pulse of tidally influenced shallow-marine siliciclastic deposition under similar conditions to those of the Tayan Siltstone further south.

The pattern of southwest- to west-trending facies belts derived from deep boreholes (Andrews 1991), passing from fluvial and intertidal siliciclastic facies in south Jordan to shallow marine carbonate and intertidal siliciclastic environments in central and north Jordan, is consistent with a progressive onlap during Tayan to Numayri time. The carbonate platform can be traced in the sub-surface of north Syria (Best *et al.* 1993), a distance of about 700 km from the location of the palaeoshore line in south Jordan (Fig. 2). The maximum transgression (maximum flooding) resulted in deposition of the main Numayri carbonate in the type area, passing southwards into intertidal and fluvial siliciclastic strata (Wadi Kusheiba Sandstone). A subsequent regressive low-stand of sea-level (see Regional Correlation, below) resulted in an increased influx of sandy sediment during deposition of the Hanneh unit in the type area. However, boreholes in north Jordan indicate that stratigraphically younger phases of carbonate deposition may have continued in those areas located farther offshore.

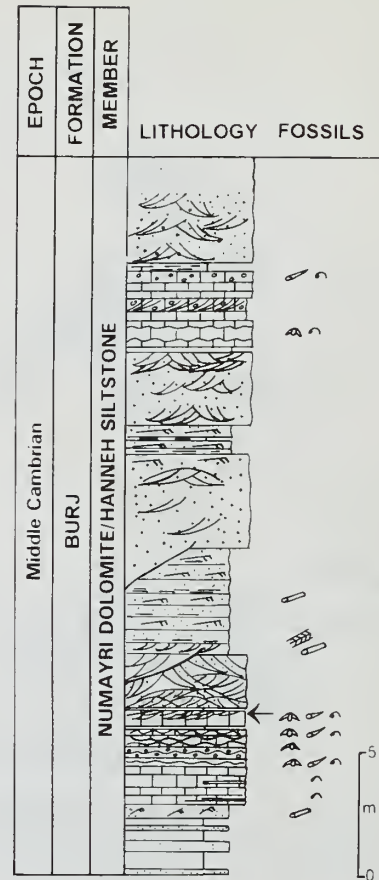


Fig. 6 Stratigraphical section of the upper part of the Burj Formation at Wadi Zarqa Ma'in, northern Dead Sea. Key as for Fig. 5, but note the difference in the vertical scales. Arrow shows the level with the trilobites figured herein.

## FAUNAS

Fossils are reported from the following sites:

1. WADI ZARQA MA'IN. A section 800 m north of Wadi Zarqa Ma'in (PNG 204.4:501.3) contains thin calcarenite beds. These have yielded:

*'Hyalolithes' kingi* Richter & Richter, 1941 [type locality]

*Kingaspis campbelli* (King, 1923) [type locality; described herein]

*Palaeolenus antiquus* (Chernysheva, 1956) [described herein]

*'Hyalolithes' kingi* is apparently identical to *Hyalolithes fouchouensis moabiticus* described from the same locality by Picard (1942), presumably in ignorance of the Richter & Richter (1941) paper.

2. WADI RIMEILEH, King's (1923) locality λ3 (PNG 201:061), 1.6 km south of Wadi 'Esal' (=Issal); this is approximately the same locality as Wadi At Tayan (Fig. 3), described herein. From micaceous siltstone:

*Onaraspis palmeri* (Parnes, 1971)

It appears that the original material of *Realaspis? orientalis*

- (Picard, 1942) came from the same locality, though not necessarily the same stratum.
3. WADI QUNAI. Section 2 km east of Arab Potash Works, Safi (PNG 201.5:055.6) (Fig. 3):  
Lingulate? brachiopod with divaricate sculpture  
'*Hyolithes*' cf. *kingi* (Richter & Richter, 1941)  
*Realaspis* sp. nov. [described herein]  
*Redlichops blanckenhorni* Richter & Richter, 1941 [described herein]
  4. WADI SARAMUJ (PNG 198:047) (Fig. 3):  
*Psiloria alata* (King, 1923) [type locality]  
*Trematosia radifer* (Richter & Richter, 1941) [type locality]  
'*Hyolithes*' sp.  
The brachiopods were described by Cooper (1976).
  5. KHIRBET EL-BURJ (PNG 198:047) (Fig. 3):  
*Trematobolus palastinensis* Richter & Richter, 1941 [type locality]  
*Trematosia radifer* (Richter & Richter, 1941)  
'*Hyolithes*' sp.  
*Hesa problematica* Richter & Richter, 1941 [type locality]  
*Redlichops blanckenhorni* Richter & Richter, 1941 [type locality; described herein]
  6. AL ABRASH. Ghor-es-Safi: exact locality and PNG reference not known.  
*Psiloria dayi* Cooper, 1976 [type locality]  
*Trematosia radifer* (Richter & Richter, 1941)  
*Kingaspidoidea* cf. *obliquoculatus* Geyer, 1990b [described herein]

Farther south, from the Timna area in Israel, Parnes (1971) described several trilobites, namely species of *Strenuella* and the new genus *Timnaella*, together with '*Myopsolenus palmeri*' Parnes for which the type locality is Har 'Amram, south of Timna. The material is fragmentary and poorly preserved, and correlation is uncertain, but we have confirmed Parnes' (1971: 204) suggested identification of King's 'asaphid' from Wadi Rimeileh with his *Onaraspis* [*Myopsolenus*] *palmeri*, which we take to be of about the same age as the beds at Wadi Qunai. Cooper (1976) described nine brachiopods from the Timna area, none of which have yet been identified from around the Dead Sea.

## REGIONAL CORRELATION

The problem of recognising the Early-Middle Cambrian boundary is discussed by Geyer & Palmer (1995). If the presence of *Paradoxides* s.l. is used to recognise the Middle Cambrian, the appearance of *Acadoparadoxides* in Morocco at a level considerably lower than that indicated by earlier workers (e.g. Hupé 1960) implies that previous records of Lower Cambrian faunas may now need to be re-classified as Middle Cambrian – an opinion already expressed by Öpik (1975). The interval affected approximates to the lower Amgan (Table 1) of the Siberian succession and includes the *Protolenus* Zone of North Atlantic (Avalonian) successions. At present no internationally agreed standard has been adopted (Geyer & Palmer 1995: 462), but in the present paper the Moroccan usage of Geyer (1990a) and Geyer & Palmer (1995) is adopted to facilitate correlation in the Mediterranean area. In 1990 Geyer took the base of the Middle Cambrian at the base of the *Hupeolenus* Zone, although Geyer & Palmer (1995) showed *Paradoxides* s.l. extending down into its uppermost part only. In the following discussion reference is made to the stratigraphical successions shown in Table 1.

WADI ZARQA MA'IN. The two trilobites recorded from Wadi Zarqa Ma'in are known elsewhere. In Siberian sections on the rivers Amga and Lena *Palaeolenus antiquus* characterises the *antiquus* Zone, the basal zone of the Middle Cambrian as traditionally recognised there, and the range of *Schistocephalus juvenis* lies immediately above that of *P. antiquus*. In Morocco *S. cf. juvenis* occurs with *Acadoparadoxides* in the *Cephalopyge* Zone (Sdzuy 1995), and it is assumed that the *P. antiquus* Zone correlates with the underlying beds, i.e. approximately the *Hupeolenus* Zone. *Kingaspis campbelli* is recorded from Morocco (Geyer 1990b: 44) in strata questionably referred to the *frequens* Zone (Table 1), the third zone above the base of the Middle Cambrian as recognised by Geyer (1990a). Assuming that the more reliable evidence is the *Palaeolenus-Schistocephalus* sequence, the upper part of the Burj Formation at Wadi Zarqa Ma'in is correlated approximately with the *Hupeolenus* Zone.

SOUTHERN END OF DEAD SEA. It is more difficult to assess the age of the Burj Formation in the type area as nearly all the fossils are known only from the Dead Sea and Rift Valley region. *Kingaspidoidea* cf. *obliquoculatus* is closest to a species known from the *Hupeolenus* Zone in the lowest Middle Cambrian of Geyer's (1990a) Moroccan sequence. The metadoxidid *Realaspis*, which has a relatively distinctive pygidium, is known by the type and only described species *R. strenoides*; this genus, with *Pseudolenus*, characterises the base of the Bilbilian in Spain (Liñán *et al.* 1993), a level that has been correlated with the the lowest Middle Cambrian of Geyer, namely the *Hupeolenus* Zone. The fragments of *Onaraspis palmeri* (Parnes) from Wadi Rimeileh (= Wadi At Tayan) suggest probable correlation of the Burj Formation with the Mikhrat and/or Upper Hakhilil members of the Timna Formation of the Timna area (Parnes 1971). All the other species described from that region appear to be endemic and the genera they represent are either new or stratigraphically long-ranging (Parnes 1971; Cooper 1976).

DISCUSSION. The stratigraphical resolution of these faunas for wider correlation is not very good, but, so far as can be judged, they all indicate a comparatively restricted stratigraphical level close to the Lower-Middle Cambrian boundary as recognised by Geyer (1990a) and Geyer & Palmer (1995). They indicate correlation of the Burj Formation with the *Hupeolenus* Zone of Morocco, probably with the lower part of the Bilbilian Stage of Spain, and with the lowest part of the Amgan Stage in Siberia. Sdzuy (1995) demonstrated the correlation of overlying strata: the *Cephalopyge* Zone of Morocco with the lowest Leonian of Spain and the middle zone of the Amgan (Table 1).

According to Liñán & Gámez-Vintaned (1993: 838), strata in Spain show evidence of what they term the Daroca Marine Regression during the Bilbilian Stage at a level somewhat above its base, and they attribute it to a eustatic fall of sea-level. If our correlation of the Burj Formation with the lower Bilbilian is correct, it is probable that it was the Daroca Regression which re-established fluvial deposition over Jordan and on the Arabian Craton. The sea retreated towards Turkey where, although correlatives of the *Hupeolenus* Zone have not been recorded, faunas of Middle Cambrian age are well described by Dean and his co-workers (e.g. Dean & Özgül 1994): such faunas commence with approximate correlatives of the *Cephalopyge* Zone, and range up through the Middle Cambrian, and confirm the persistence of marine deposition in areas to the north of Jordan and Syria.



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**SYSTEMATIC DESCRIPTIONS**


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Superfamily **REDLICHIOIDEA** Poulsen, 1927

Family **REDLICHIIDAE** Poulsen, 1927

?Subfamily **PARAREDLICHIINAE** Hupé, 1953

Genus **REDLICHOPS** Richter & Richter, 1941

TYPE SPECIES. *Redlichia (Redlichops) blanckenhorni* Richter & Richter, 1941, by original designation.

DISCUSSION. *Redlichops* is a poorly known genus. When Chang [=Zhang] (1966) and Zhang *et al.* (1980: 79) reviewed redlichiid trilobites they referred *Redlichops* with doubt to the Pararedlichiinae, mainly because both the anterior and posterior ends of the palpebral lobe are set rather far from the glabella. Even so, *Redlichops* differs from other Pararedlichiinae in the great width of the interocular area of the fixigena and in the recurved palpebral lobe, features matched or exceeded only by the aberrant Metaredlichiine *Jingyangia* (Zhang

*et al.* 1980: pl. 31, figs 7, 10, 11). However, the glabella of *Redlichops* is not comparable with the parallel-sided or clavate glabella of the Metaredlichiinae, and the genus is here retained provisionally in the Pararedlichiinae, following Chang (*in* Whittington *et al.*, 1997: 440).

*Redlichops blanckenhorni* Richter & Richter, 1941

Figs 7–13

1941 *Redlichia (Redlichops) blanckenhorni* Richter & Richter: 15, pl. 2, figs 1, 2, 4, 5?, 6a (*non* figs 3, 6b) [synonymy, description].

1997 *Redlichops (R.) (sic) blanckenhorni* Richter & Richter; Whittington *et al.*: 441, fig. 280.1.

MATERIAL. The species is based on fragmentary material from the type locality, Khirbet el Burj. Dr W. Struve kindly made available plaster casts of the holotype (Senckenberg Museum, Frankfurt-am-Main X1287a; Fig. 7) and a paratype (X1287b). New material from Wadi Qunai referred to the species is somewhat weathered but is



Figs 7–13 *Redlichops blanckenhorni* Richter & Richter. 7, plaster cast (It.26207/1) of holotype, Senckenberg Museum X1287a,  $\times 4$ , Khirbet El-Burj. 8–13, Wadi Qunai, Safi. 8, librigena It.26211/5,  $\times 4$ . 9, large cranidium, It.26209/1,  $\times 4$ . 10, external mould of rostral-hypostomal plate, associated with *Realaspis* sp. nov. (Fig. 16), It.26212/1,  $\times 4$ . 11a, b, small cranidium It.26209/3, associated with fragmentary pygidium It.26209/4 attributed to the same species; 11a  $\times 3.5$ , 11b  $\times 4$ . 12a, b, top and side views of cranidium, It.26209/6,  $\times 4$ . 13, cranidium It.26209/2,  $\times 4$ .



more complete, and consists of nine cranidia and some cranial fragments, a rostral-hypostomal plate, three librigenae, and a fragmentary pygidium tentatively referred to this species (BM It26209, It26211-3).

**DESCRIPTION AND DISCUSSION.** The new specimens show that, despite their fragmentary material, the Richters' description and reconstruction of the cranidium are generally correct. The preglabellar field is slightly longer than they showed it, and in small specimens is crossed by a preglabellar ridge or plectrum; the anterior border bears faint terrace-lines parallel to the margin. The palpebral lobes in the new material are more evenly curved than in the reconstruction by Richter & Richter (1941: pl. 2, fig. 6a); in the new material they do not show the distal narrowing described by Richter & Richter, nor is this very evident in their holotype (Fig. 7). The palpebral-ocular ridge is not joined anteriorly to the glabella, nor is a parafrontal band evident; this ridge appears to slope backwards more steeply in the holotype than in the similarly sized specimen in Fig. 9, but there is some variation in this feature among the various specimens on block It.26209 (Figs 9, 11-13). The postocular section of the facial suture is very short. Where unweathered the surface is seen to be finely granulose.

The rostral-hypostomal plate (Fig. 10) is abraded but resembles those of other Redlichidae (Zhang *et al.* 1980: 69). If correctly assigned to this species, it shows that *Redlichops* is conterminant. The presence of a plectrum crossing the preglabellar field is commonly seen in trilobites with conterminant hypostomes.

The librigena (Fig. 8), confidently assigned because the course of the facial suture corresponds to that of the cranidium, is narrow, the border and the field within the border being of about the same width; in this it differs from the large fragment figured by Richter & Richter (1941: pl. 2, fig. 3), which we exclude from the species.

One fragmentary pygidium (Figs 11a-b) has a long, poorly segmented axis and the pleural field nearly as wide as the axis. There is one weak pleural groove. The surface is finely granulose and has fine striae sub-parallel to the margin. The sculpture is much less conspicuous than that of the pygidia from the same beds assigned to *Realaspis*.

The broad interocular areas of the fixigenae and the recurved palpebral lobe make *Redlichops blanckenhorni* a distinctive taxon, and no closely similar species is known. At a comparable size the Pararedlichiiine *Eoredlichia yaoyingensis* (Kobayashi) has narrower interocular fixigenae and shorter palpebral lobes, but immature forms have relatively longer, more curved palpebral lobes (Zhang *et al.* 1980: pl. 35, fig. 10), suggesting that the peculiarities of *Redlichops* may be genetically derived.

**HORIZON.** *Redlichops blanckenhorni* is known only from Jordan and its biostratigraphical significance is not established. Pararedlichiiinae occur typically in the low Lower Cambrian but are not known to range into the Tissafin Stage which is low Middle Cambrian in Geyer's (1990a) usage. However, *Redlichops* is only doubtfully referred to the Pararedlichiiinae, and is here considered to lie close to the Lower-Middle Cambrian boundary, as originally suggested by Richter & Richter (1941: 27).

#### Subfamily METADOXIDINAE Whitehouse, 1939

##### Genus *REALASPIS* Sdzuy, 1961

**TYPE SPECIES.** *Realaspis strenoides* Sdzuy, 1961, by original designation.

**DISCUSSION.** Sdzuy (1961) placed *Realaspis* in the Neoredlichii-

inae, and Chang (*in* Whittington *et al.*, 1997: 458) referred it to the subfamily Resseropinae, family Saukiandidae. However, the relatively broad interocular area of the fixigenae and the short palpebral lobe favour reference to the Metadoxidinae, as suggested by Öpik (1968: 151).

##### *Realaspis* sp. nov.

Figs 15-18

**MATERIAL.** Four incomplete cranidia, one librigena, two pygidia, and several doubtful granulose fragments, associated with *Redlichops blanckenhorni* at Wadi Qunai (BM It26210-2).

**DESCRIPTION.** Glabella tapered, rounded in front; glabellar furrows very weak, seen on the largest cranidium as faint indentations in the side of the glabella; occipital ring with small spine (Fig. 15a), occipital furrow weak. Anterior border strong, with striae sub-parallel to anterior margin. Preglabellar field practically absent, forming a depressed groove shorter than border. Palpebral-ocular ridge strong, oblique, not confluent with glabella, but in the smaller figured cranidium (Fig. 16) seems to extend into a parafrontal band. The eye extends approximately from the second glabellar furrow (S2) to the occipital furrow (SO). At level of anterior end of eye the width of cranidium is nearly three times the glabellar width at the same level; at the posterior end of the eye it is a little more than twice as wide. Interocular area of fixigena has a marked elongated interocular swelling (Pillola 1993: 859) close to the glabella. Preocular section of facial suture short, straight, subparallel or slightly divergent forwards to the anterior border furrow; posterior section very short. Surface with coarse but not very closely spaced granules. Several fragments on the same bedding planes (Fig. 17) bear the same sculpture and indicate the presence of much larger individuals than the figured specimens.

Two pygidia (Fig. 18) associated with *R. blanckenhorni* and *Realaspis* sp. nov. are referred to the latter because their granulation and coarsely striate margins resemble those of the cranidia assigned to *Realaspis*. Outline rounded, with length two-thirds of the width. The axis occupies less than half the width and nearly the whole length of the pygidium and has one distinct and one obscure axial ring. The pleural regions have one or two pairs of weak furrows and the margin is entire; there is no semi-ankylosed anterior segment. Surface granulose, with striae near to and subparallel with the margin.

**DISCUSSION.** The pygidia of the present taxon are fairly distinctive, most resembling those of the Neoredlichiiinae and some Metadoxidinae, especially *Realaspis strenoides* Sdzuy (1961: pl. 4, figs 18-24), though it has 1-2 rather than 3 axial rings. The cranidium is also similar in outline to *R. strenoides* (Sdzuy 1961: 536 (254), pl. 4, figs 1-12), but shows more marked relief: in *R. strenoides* the anterior border and palpebral-ocular ridge are not so strong, the border furrow in front of the glabella is narrower, the eye is shorter, no interocular swellings are seen and there is no occipital spine (Whittington *et al.*, 1997: fig. 249.1a). The sculpture in *R. strenoides* is unknown, so the granulation of the present species and the striae on the anterior border cannot be compared.

The present cranidia resemble some bigotinids related to *Hupetina* Sdzuy, 1978, from the lowest trilobite zone in the Issendalen Stage of the Moroccan Cambrian (Geyer 1990a). They differ from *Hupetina antiqua* Sdzuy in having weaker glabellar furrows, a stronger anterior border and longer preglabellar field; the interocular swelling is larger and closer to the glabella than in Sdzuy's (1978: pl. 1, fig. 7) paratype. In proportions and the weak glabellar furrows the present material is more like the unnamed cranidium from the Lemdad section A2, figured by Sdzuy (1978: fig. 3, top left), though that form

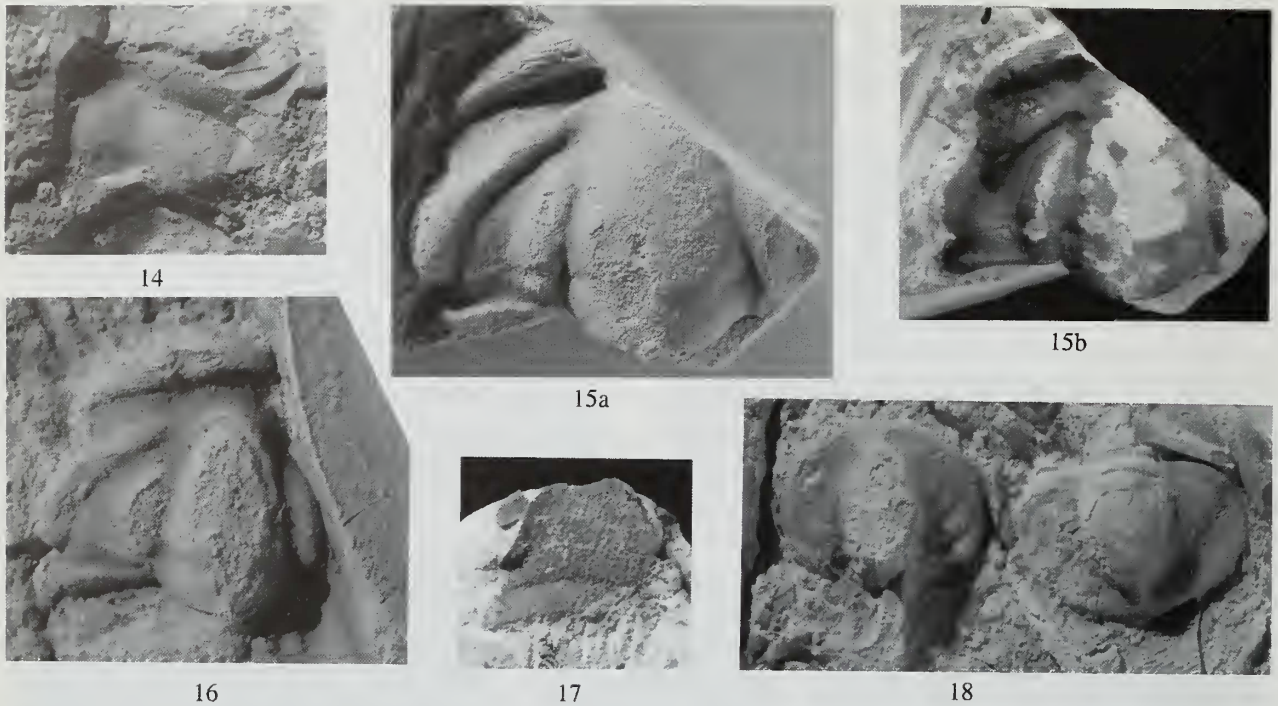


Fig. 14 *Hesa problematica* Richter & Richter, **holotype**: plaster cast (It.26207/2) of cranial fragment, showing parts of the preocular suture and anterior border, Khirbet El-Burj, Senckenberg Museum X1287a,  $\times 4$ .

Figs 15–18 *Realaspis* sp. nov., Wadi Qunai, Safi. 15a, b, abraded cranidium It.26210/1; 15a, whitened, shows the interocular swelling, occipital furrow and occipital node,  $\times 3.5$ ; 15b, unwhitened, shows the course of the facial suture,  $\times 3$ . 16, small cranidium It.26212/2,  $\times 8$ . 17, fragment of fixigena of large cranidium attributed to this species, showing granulation, It.26209/8,  $\times 3$ . 18, two pygidia, It.26211/1 (right) and 26211/2 (left),  $\times 4$ .

has more divergent preocular facial sutures and no interocular swelling is shown. Few bigotinid pygidia have been described, but those of the present species are unlike those of *Bigotina* itself (Pillola 1993: pl. 3, figs 3, 8).

The holotype of *Hesa problematica* Richter & Richter (1941: pl. 2, fig. 7) is a fragment of a large trilobite on the same block as the holotype of *Redlichops blanckenhorni*. It is unsuitable to be the formal representative of a distinct genus, but shows a slightly divergent preocular suture and a frontal border (Fig. 14) striated in much the same way as our Fig. 15; it differs because the glabella seems to indent the frontal border, a difference that seems too great to be attributed to the stage of growth.

*Protolenus orientalis* Picard (1942: 1, pl. 2, figs 1, 2) was revised by Parnes (1971: 186, pl. 1, figs 1–4), who figured two cranidia, including Picard's specimen. He referred the species to *Resserops* (*Richterops*) Hupé, 1953, though the form of the palpebral lobe is more compatible with *Realaspis*. Our material differs from *R. orientalis* in having a stronger, striated anterior border, a stronger border furrow, wider interocular fixigenae with stronger interocular swellings, and a coarser granulation. However, *Realaspis orientalis* seems to show greater resemblance to *Hesa problematica*, but the type material of the latter is so fragmentary that full comparison cannot be made.

**HORIZON.** *Realaspis* sp. nov. occurs with *Redlichops* (q.v.) and there is no independent indication of its horizon. The most similar species, *Realaspis strenoides*, occurs at Los Cortijos, in strata of the Galician-Castilian Zone near Toledo, central Spain (Sdzuy 1961: 594), where it occurs with *Pseudolenus*, *Kingaspis* cf. *velatus*

Sdzuy, 1961, and protolenids, which suggest the Bilbilian Stage (Liñán *et al.*, 1993: 822).

#### Genus *ONARASPIS* Öpik, 1968

**TYPE SPECIES.** *Onaraspis somniurna* Öpik 1968, by original designation.

#### *Onaraspis palmeri* (Parnes, 1971) Figs 19, 20

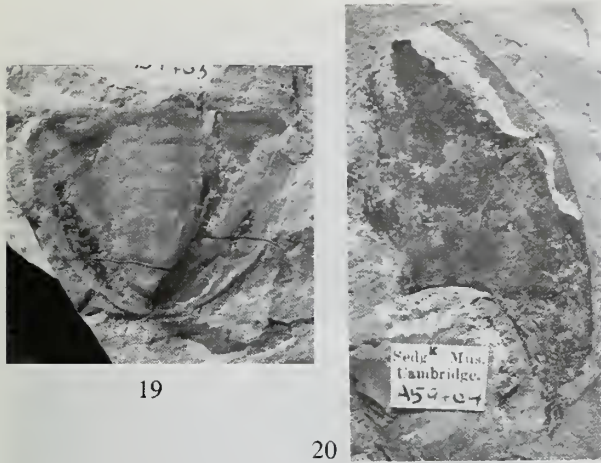
1923 Asaphid; King: 511 [briefly described as 'of a distinctly Asaphid type', no figure].

1971 *Myopsolenus palmeri* Parnes: 202, pls 3, 4 [described].

1975 *Myopsolenus palmeri* (Parnes); Öpik: 8, 9 [compared with *O. somniurna*; the reference on p. 8 to '*Myopsolenites*' is a misprint].

**DISCUSSION.** The type material, from Har 'Amram south of the Timna area, is poorly preserved and it is difficult to ascertain the characters of the species. Geyer (1990b: 175) pointed out that Parnes' reconstruction of the cranidium differs in several respects from typical *Myopsolenus*, and suggested instead that it might be a member of the Bathynotidae. Considering the cranidial features, it is more like some *Metadoxides* (Pillola 1991: pl. 10, fig. 6), but the pygidium of *O. palmeri*, which has an axis of several segments and pleural fields with a broad border, is distinct from that of *M. armatus* (Meneghini), well figured by Pillola (1991: pl. 9, fig. 4), and more like that of *Onaraspis*. Öpik (1975: 9) suggested that *Myopsolenus palmeri* was 'the same or . . . closely related' to *O. somniurna*. We





Figs 19, 20 *Onaraspis palmeri* (Parnes), from King's (1923) locality 83, Wadi Rimeileh. 19, pygidium, external mould, Sedgwick Museum A.59463. 20, librigena, the infill between dorsal surface and doublure shows white, Sedgwick Museum A.59464. Both unwhitened.  $\times 1.3$ .

accept the generic reference but the observed differences are probably of specific significance: for example *O. palmeri* has a longer frontal area and the pleural field of the pygidium tapers backwards less strongly.

King's material from Wadi Rimeileh (Figs 19, 20) consists of a large librigena, some pleural fragments and two pygidia, of which one is complete. The specimens are fairly well preserved in siltstone and, though somewhat flattened, show granulose sculpture. The pygidium appears to agree with that of *O. palmeri* but is longer in proportion than that of *O. somniurna*, though it may be more similar to Öpik's (1968: 159) *Onaraspis* sp. A.

HORIZON. Parnes (1971: pls 3, 4) recorded *O. palmeri* from the lower and upper parts of the Timna Formation, respectively from the upper part of the Hakhliil Member at Timna and from beds at Har 'Amram that are correlated with the Mikhrot Member. The specimen from Wadi Rimeileh is from a siltstone interval in the Burj Formation, but its stratigraphical relationship to other localities is unknown.

Superfamily ELLIPSOCEPHALOIDEA Matthew, 1887

Family ELLIPSOCEPHALIDAE Matthew, 1887

Subfamily ELLIPSOCEPHALINAE Matthew, 1887

Genus *KINGASPIS* Kobayashi, 1935

TYPE SPECIES. *Anomocare campbelli* King, 1923, by original designation.

DISCUSSION. Geyer (1990b: 102) placed *Kingaspis* close to *Ellipsocephalus*, regarding the separate family (or subfamily) Kingaspididae (or Kingaspidinae) as superfluous. He discussed the type species, *K. campbelli* (King) and described several other species of *Kingaspis* and of the closely related genus *Kingaspidoides* Hupé, 1953. All species of these genera have features of the cranidium effaced on the external surfaces, but axial and glabellar furrows are generally visible on internal moulds. The weakness of these furrows makes measurements taken from them rather imprecise, hampering morphological comparisons, but the form of the glabella, which has concave sides, expanded anterolateral corners and 4 or 5 pairs of furrows, is consistent.

*Kingaspis campbelli* (King, 1923)

Figs 21–26

- 1923 *Anomocare campbelli* King: 511, figs 3, 4 [described, illustrated with line-drawings].  
 1935 *Kingaspis campbelli* (sic) (King); Kobayashi: 196, pl. 23, figs 9, 10 [assigned to *Kingaspis*; poor photographs of King's specimens, the cranidium is incorrectly restored].  
 1990b *Kingaspis campbelli* (King); Geyer: 104, pl. 15, fig. 11, pl. 17, figs 8–10 [Moroccan specimens described and discussed, with full synonymy].

MATERIAL. King's syntype material is preserved in the Sedgwick Museum, Cambridge, and from that the cranidium SM A.1311, figured by King (his fig. 3), is here selected as lectotype (Figs 21a–c herein). Topotypic material is held in other museums (Hebrew University of Jerusalem; Senckenberg Museum, Frankfurt; Natural History Museum, London); more recently Dr J. H. Powell collected further specimens, one of which is figured here (Fig. 25).

DISCUSSION. Topotypic material is well preserved and agrees with Geyer's description. He remarked that *K. campbelli* has a relatively wider cranidium (1.3 times the length) than other species of the genus. There is slight variation in transverse convexity and in the evenness of the curvature in sagittal section.

Geyer excluded the pygidium described by King from the species, but because it is the only kind of pygidium found with monospecific associations of the cranidia of *K. campbelli*, King probably originally associated them correctly. King's large paralectotype is shown here (Fig. 22). A smaller well preserved example (Fig. 26) is 5.0 mm long and estimated to have been 13 mm wide; axis more than a quarter of the total width, convex, with 3 axial rings and a trace of a fourth; pleural regions with 4 pleural furrows and three interpleural grooves; border narrows slightly backwards.

Originally described from the Burj Formation at Wadi Zarqa Ma'in, topotypic specimens have since been figured many times (see Geyer 1990b: 104).

HORIZON. At Wadi Zarqa Ma'in *K. campbelli* is in earliest Middle Cambrian beds associated with the lower Amgan species *Palaeolenus antiquus* (Chernysheva), discussed below. In Morocco it is questionably recorded from the *frequens* Zone.

Genus *KINGASPIDOIDES* Hupé, 1953

TYPE SPECIES. *Kingaspidoides armatus* Hupé, 1953, by original designation.

DISCUSSION. *Kingaspidoides* was originally instituted for kingaspidids with an occipital spine (Hupé 1953), but Geyer (1990b: 110) emended the diagnosis and distinguished the genus from *Kingaspis* by the relatively uneven convexity of the cranidium in transverse section.

*Kingaspidoides* cf. *obliquoculatus* Geyer, 1990 Figs 27, 28

cf. 1990b *Kingaspidoides obliquoculatus* Geyer: 118, pl. 18, figs 1–15.

MATERIAL. Three cranidia from Al Abrash, Ghor-es-Safi, BM In24056-8, collected by Dr A. E. Day in 1909. Associated with *Psiloria dayi* Cooper (1976: 283), for which this is the type locality.

DESCRIPTION AND DISCUSSION. The glabella has independent transverse convexity (Fig. 28e). Interocular area of fixigena scarcely convex, slopes down to palpebral lobe which is short, the posterior end lying well forward of SO. Glabella relatively narrow; at a line



**Figs 21–26** *Kingaspis campbelli* (King), Wadi Zarqa Ma'in. **21a–c**, lectotype, top, front and side views of exfoliated cranidium, showing glabella and independent convexity of occipital ring, Sedgwick Museum A.1311,  $\times 3$  (figured King 1923: fig. 3). **22**, paralectotype, large pygidium, Sedgwick Museum A.1310,  $\times 3$  (figured King 1923: fig. 4a). **23–26** are topotypes; **23a, b**, top and front views of testate cranidium (23b, unwhitened, shows the even transverse convexity of the cranidium), In.22997/1,  $\times 3$ ; **24a–d**, side, top, oblique and front views of partly exfoliated cranidium (24a and 24d, unwhitened, show the even convexity, 24b and 24c show the glabella and frontal border), In.22996,  $\times 3$ ; **25a, b**, top and side views of partly exfoliated cranidium (25a shows the difference between the internal and external surface), It.26231, 25a  $\times 4$ , 25b  $\times 3$ ; **26**, latex cast of external mould of pygidium, In.22997/2,  $\times 3$ .

**Figs 27, 28** *Kingaspisoides cf. obliquoculatus* Geyer, 'Al Abrash, Ghor-es-Safi' (exact locality uncertain). **27**, internal mould of fragmentary cranidium, In.24058,  $\times 3$ . **28a–e**, abraded testate cranidium (28a, 28b, side and top views, whitened, showing the independent convexity of the glabella; 28c–e, side, top and front views, unwhitened, showing the course of the facial suture and transverse convexity of the glabella), In.24056, 28a, 28b  $\times 3.5$ , 28c–e  $\times 3$ .



through the palpebral lobes it is <40% of cranial width (Fig. 28b). No occipital spine or node. Frontal area relatively long, nearly 25% of cranial length. Surface smooth, but the internal mould shows tiny pits (= granules on the parietal surface of the cranidium) and caeca on the preglabellar field.

Among *Kingaspidoidea* without an occipital spine, *K. obliquoculatus* differs from *K. neglectus* Geyer (1990b: 120) in having a shorter and narrower glabella, and from *K. borjensis* Geyer (1990b: 122) in having a shorter palpebral lobe which does not extend back to the level of SO.

**HORIZON.** Burj Formation, Ghor-es-Safi. *K. obliquoculatus* was originally described from the Asrir Formation (*Hupeolenus* Zone) of the Fougara section in the Anti-Atlas Mountains, Morocco.

#### Family PALAEOLENIDAE Hupé, 1953

**DISCUSSION.** The Palaeolenidae were discussed and briefly characterised by Geyer (1990b: 67). The glabella is well defined and tends to be clavate and typically shows four pairs of glabellar furrows; the posterior pair (S1) curve slightly inwards and backwards, S2 and S3 are nearly transverse, short and not connected across the glabella, and S4 is short and slightly oblique inwards and forwards. In *Palaeolenus lantenoisi* Mansuy, 1912, the glabella is almost parallel-sided but in *P. douvillei* Mansuy, 1912, the type of the genus, the glabella is slightly clavate; in both those species the preocular sections of the facial suture are approximately parallel. In *P. deprati* Mansuy, 1912, the type species of *Megapalaeolenus* Chang, 1966, the glabella is clavate and the preocular sutures diverge forwards. It is doubtful whether *Megapalaeolenus* should be maintained as an independent genus.

#### Genus PALAEOLENUS Mansuy, 1912

**DISCUSSION.** The species described below was originally assigned to the genus *Schistocephalus* Chernysheva, 1956, which has been regarded as a member of the Family Paradoxididae. The distance from the anterior end of the palpebral lobe to the glabella, connected by an eye-ridge, and the presence of a parafrontal band (Fig. 29a), are features of various genera commonly referred to the superfamily Ellipsocephaloidea (Geyer 1990b). The type species of *Schistocephalus*, *S. enigmaticus* Chernysheva (1956: pl. 30, figs 1, 3), has a parallel-sided glabella on which the glabellar furrows S1 to S3 are arched backwards and joined strongly across the mid-line; S4 lies relatively close to S3 and is very short. The anterior part of the glabella appears transversely oval. Other species of *Schistocephalus* have been described which show rather diverse glabellar morphology (Chernysheva 1971: pls 6, 7). Most of them have a slightly clavate glabellar with a semi-circular frontal lobe; some of them, such as *S. juvenis* Chernysheva, 1956 (Sdzuy 1995: pl. 1, fig. 8) and *S. amzassiensis* Fedjanina (in Chernysheva 1971: pl. 6, figs 8–13), share with *S. enigmaticus* the strongly transglabellar furrows S2 and S3. See also *S. ex gr. juvenis* well figured in Egorova *et al.* (1976: pls 32–34). In some other early species such as *S. antiquus* Chernysheva, 1956, and *S. tchernyshevae* Bognibova (in Chernysheva 1971) these furrows do not join across the glabella. The latter forms are closer in this feature to *Palaeolenus* (especially species that have been referred to *Megapalaeolenus*) and it seems appropriate to transfer them to that genus rather than extend *Schistocephalus* unduly. Chu (1962) suggested that *Palaeolenus* is ancestral to *Schistocephalus*.

*Ferralsia* Cobbold (1935) is very similar to *Palaeolenus*, but

Geyer & Elicki (1995: 112), who reviewed *Ferralsia*, maintained that it could be distinguished from *Palaeolenus* by its shorter and more regularly spaced glabellar furrows; in at least some species of *Palaeolenus* S3 and S4 are closer together than S1 and S2. Furthermore, *Ferralsia* tends to have a longer preglabellar field and narrower interocular fixigenae. However, in view of the variation shown by species of *Palaeolenus* and *Schistocephalus*, these features, even if they are considered to be of generic value, may be difficult to apply.

It is possible that the genus *Gigoutella* Hupé, 1953, would be an appropriate reference for some of those taxa with discontinuous glabellar furrows, but regrettably the genus is known only from a single schematic line-drawing (which is misleading according to Geyer & Elicki 1995: 112). As attempts to examine the original material have been unsuccessful, the nature and relationships of the only described species, *G. atlasensis* Hupé (1953), remain to be elucidated, but it may prove to be a senior synonym of *Megapalaeolenus* (and, following Sdzuy (1995), *Schistocephalus* if a broad view is taken of that genus), or a junior synonym of *Ferralsia*.

#### *Palaeolenus antiquus* (Chernysheva, 1956) Figs 29–38

- 1956 *Schistocephalus antiquus* Chernysheva: 150, pl. 30, fig. 6 [cranidium figured, compared with *S. enigmaticus*].  
 1976 *Schistocephalus antiquus* Tchernysheva [sic]; Egorova *et al.*: 74, pl. 23, figs 11–14, pl. 25, figs 1, 2, pl. 28, fig. 1 [figures of several cranidia].  
 1995 *Schistocephalus antiquus* Chernysheva; Sdzuy: pl. 1, fig. 9 [new figure of holotype].

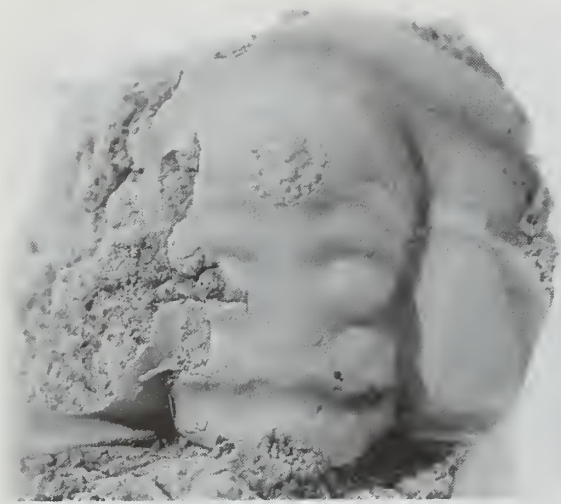
**NEW MATERIAL.** Sixteen cranidia (mostly fragmentary), two librigenae and three small pygidia, all from a calcarenite bed (Fig. 6) in a culvert, 0.8 km N of Wadi Zarqa Ma'in (BM It26214–30).

**DESCRIPTION.** Glabella (including occipital ring, LO) clavate, occupies 85% of cranial length; forward of L2 widens to a maximum opposite S4, where it is about 120% of the width of L1. Glabellar lobes L1 to L4 become progressively shorter (exsag.); the frontal lobe is well rounded anteriorly. LO without node. S1 slightly curved inwards and backwards, with a tendency to bifurcate medially; S2 approximately transverse but each furrow forms a slight convex curve anteriorly; S3 similar to S2 but extends inwards and slightly forwards; S4 shorter than S3, curved or more anteriorly directed. Anterior border has terrace-lines parallel to margin and is a little longer sagittally than preglabellar field. Preocular section of facial suture diverges forward at about 30° to sagittal line. Palpebral lobe one-third of cephalic length, continuous with eye-ridge which reaches glabella opposite S4 and extends forward into a narrow parafrontal band, seen on some specimens (Figs 29a, 34). Interocular area of fixigena about two-thirds of glabellar width at S1. Postocular area of fixigena not quite as wide as LO. Exterior surface granulose, most coarsely so on the median part of the glabella and the interocular fixigena, more finely on the preocular fixigena. Internal mould almost smooth, very finely pitted, indicating very fine granulation on the parietal surface of the exoskeleton.

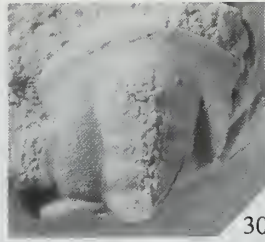
Librigena narrow, the border occupying nearly half the total width. Genal spine very short (Fig. 36).

Pygidium small, with wide short axis having one distinct and one faint axial ring. Pleural field very small with one pleural furrow and two faint interpleural grooves (Fig. 33).

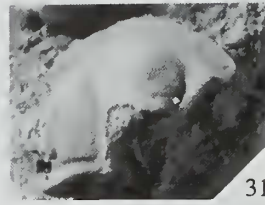
**DISCUSSION.** The specimens from Wadi Zarqa Ma'in agree closely with the holotype and also the specimens figured by Egorova *et al.* (1976), except that the interocular fixigena is a little wider in some of the Jordanian specimens; the glabella widens forward less than in the holotype (Sdzuy 1995: pl. 1, fig. 9), but more than some of the



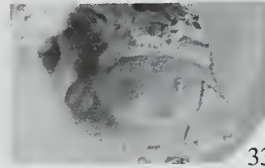
29a



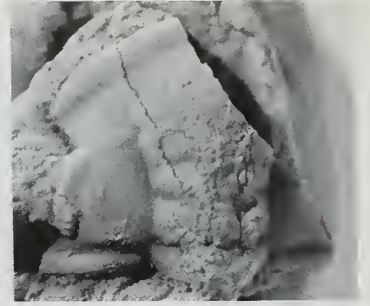
30



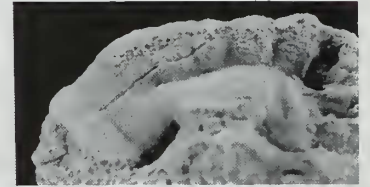
31



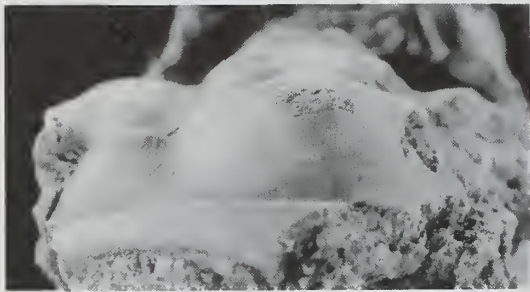
33



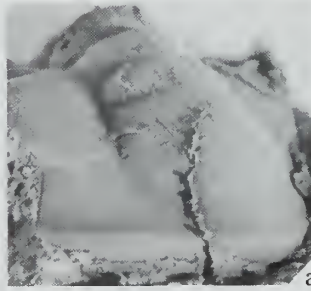
32a



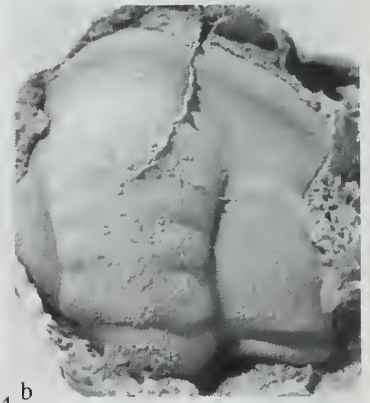
32b



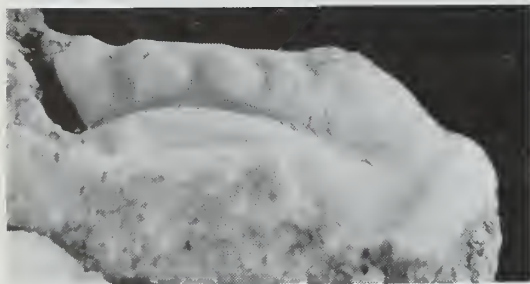
29b



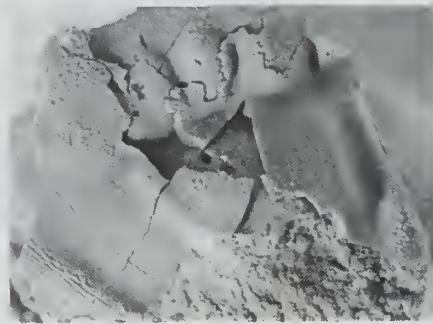
a



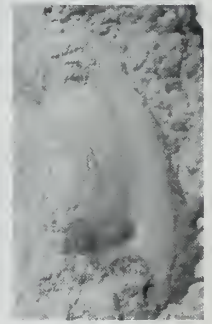
b



29c



35



36



37



38



other figured specimens (Egorova *et al.* 1976: pl. 23, fig. 11, pl. 25, fig. 1). Granulate sculpture is not seen in the holotype but is shown by Egorova *et al.* (1976: pl. 28, fig. 1).

*Palaeolenus tchernyshevae* (Bognibova in Chernysheva 1971: pl. 7, figs 6, 7, 9–12) differs from *P. antiquus* in having a narrower border and lacking a preglabellar field, so that the glabella occupies well over 90% of the cranidium length. The pygidia assigned to the two species are much alike.

Among species described from China the most similar is *Palaeolenus fengyangensis* Chu, 1962, which has an expanded glabella and divergent preocular sections of the facial suture, and has been referred to *Megapalaeolenus*. Figured material (Chu 1962; Zhang *et al.* 1980: pl. 72, figs 6–8) is of smaller cranidia than our material, but the glabella appears proportionately wider, there is a small occipital node and the preocular sutures are less divergent; the surface is not recorded as granulose.

**HORIZON.** *Palaeolenus antiquus* is recorded from the *antiquus* Zone at the base of the Amgan Stage in sections on the rivers Lena and Amga in eastern Siberia, and extends into the base of the overlying *Kounamkites* Zone (Egorova *et al.* 1976, table, p. 14); it occurs in carbonate deposits, in contrast to such species as *S. amzassensis* Fedjanina and *S. impressus* Fedjanina (both in Chernysheva 1971), which are recorded from clastic deposits (Chernysheva 1971: table, column 1). Species retained in *Schistocephalus* (*S. enigmaticus*, *S. juvenis*) are recorded from higher horizons (Chernysheva 1971).

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**Figs 29–38** *Palaeolenus antiquus* (Chernysheva), Wadi Zarqa Ma'in. **29a–c**, top, front and side views of exfoliated cranidium, showing parafrontal band, It.26214, × 4. **30–32**, small cranidia showing external surface, × 4; **30**, It.26222; **31**, It.26221; **32a, b**, top and side views of It.26216. **33**, pygidium, It.26228, × 6. **34a, b**, latex cast of external mould, oblique and top views, It.26217, × 4. **35**, fragmentary cranidium showing sculpture of fixigena, It.26218, × 4. **36**, small librigena, It.26226, × 5. **37**, fragment of large cranidium, showing glabellar furrows; the internal mould is finely pitted, It.26215, × 4. **38**, fragment of cranidium, showing palpebral lobes and postocular facial suture, It.26220, × 4.

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